KnE Engineering

RFYS
Russian Forum of Young Scientists
Volume 2018

Knowledge E
Engaging minds

Conference Paper

Improvement of Thermal and Mechanic Flow Characteristics in the Intake System of the Piston Engine with Turbocharging

L V Plotnikov

Ural Federal University named after the first President of Russia B.N. Yeltsin, 19 Mira Str., Ekaterinburg 620002, Russia

Abstract

Currently the turbocharging is actively used in piston engines to increase their technical and economic indicators. The efficiency of piston engines with turbocharging significantly depends on perfection of processes in the intake and exhaust systems. Results of experimental researches of unsteady gas dynamics and heat transfer in the intake system of the piston engine with a turbocharger are presented in the article. Studies were conducted on full-scale model of the single-cylinder engine with a turbocharger. It is shown that significant pulsations of pressure and flow occur in the intake system of the piston engine during the entire working cycle. The method of stabilization of flows in the intake system due to the controlled discharge of excess air after the turbocharger is proposed. This method will reduce the difference in the cylinders of multi-cylinder engine, reduce noise, increase reliability, and increase the efficiency of the turbocharger.

Corresponding Author:
L V Plotnikov
plotnikovlv@mail.ru

Received: 10 February 2018
Accepted: 14 April 2018
Published: 7 May 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the RFYS Conference Committee.

1. Introduction

Currently, almost all diesel internal combustion engines (ICE) have a supercharging system of any type. Proceedings of many authors are devoted to the study, evaluation and optimization of gas dynamics and heat transfer in the intake and exhaust system of the piston ICE with supercharging [1-4]. It should be noted that most studies of thermal and mechanic flows characteristics in the intake system of piston engines with supercharging was performed in a stationary mode of air flow [5-7]. However, it is clear that the processes in the intake system of the piston ICE are high frequency and non-stationary. The time intervals of the intake process in the engines are hundredths of a second. Characteristics of flows in pipes of piston engines are changed with frequency up to 100 Hz and more. It is known that the gas-dynamic non-stationary (pulsating flow) significantly affects the gas dynamics and heat transfer in hydraulic systems

[8-10]. Therefore, one of the urgent tasks is the study of thermal and mechanic flow characteristics in the intake system in terms of gas dynamic nonstationarity, as well as their improvement.

The main objectives of this work were to obtain new data about the unsteady gas dynamics and local heat transfer in the intake system of the piston engine with turbocharging, as well as to develop the method of gas-dynamic improvement of the flows in the intake system.

2. Experimental setups and measurement equipments

Experimental approach was selected as the basis due to the complexity of the study object. Therefore, the experimental setup was designed and constructed for studies of gas dynamics and heat transfer in intake system of the piston engines with a turbocharger. The general view of this setup is shown in Figure 1.

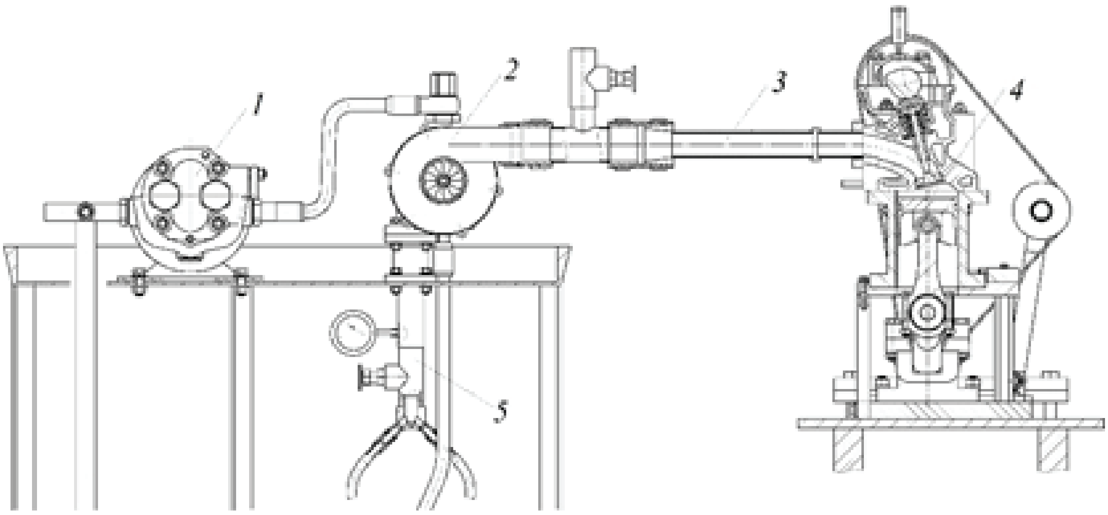

Figure 1: The experimental setup for the study of gas dynamics and heat transfer in the intake system of the piston engine with turbocharging: *1* – oil pump; *2* – turbocharger (TC); *3* – intake pipe; *4* – model of piston ICE; *5* – compressed air supply system for turbocharger drive.

The experimental setup consisted of three main parts: piston engine model, turbocharger (TC) and autonomous lubrication system. The piston part of the setup was a full-scale model of a single-cylinder engine of dimension 8.2/7.1. The crankshaft of the piston engine model was rotated by an electric motor; Its speed was adjusted by means of a frequency converter in the range from 600 to 3000 rpm. The Russian turbocharger TKR-6 was used in experiments whose rotor was rotated by compressed air from an autonomous compressor. The rotor speed of the TC varies from 35 000 to 46 000 rpm.

The automated system for collecting and processing experimental data was created on the basis of an analog-to-digital converter for measuring basic physical quantities. The constant-temperature thermo-anemometer was used to determine the instantaneous values of the air flow velocity (w_x) and the local heat transfer coefficient (α_x). The sensitive element of the sensors of the thermal anemometer was a nichrome thread with a diameter of 5 μm and a length of 5 mm. The instantaneous values of the static pressure in the intake system were measured by means of a pressure sensor from WIKA. Rotational speeds of the crankshaft n and the turbocharger rotor n_{TC} were measured using tachometers.

3. New design of the intake system of piston engine with a turbocharging

Preliminary studies of gas dynamics showed that there are significant pulsations of velocity w_x and pressure p_x of flow in the intake system on virtually all operation modes of the piston engine and turbocharger [11]. Analysis of the literature and results of experiments allowed to conclude that the cause of the intensive pulsations of the flow in the intake system of the piston ICE with a turbocharger is redundant compressor capacity relative to the piston engine. The considered pulsations negatively affect the working process of piston engines and can lead to a decrease in the filling of the cylinder with air, an increase in the noise level and a decrease in the reliability of the ICE and TC. Therefore, one of the urgent problems is to develop a method for stabilizing the air flow in the intake system of a piston engine with a turbocharger. In this case, the discharge of excess charge air after the turbocharger was proposed as a method for gas-dynamic improvement of the flows in the intake system. The scheme of the intake system with the discharge of charge air is shown in Figure 2.

Electro-pneumatic valve was used for controlled discharge of a certain part of the charge air. It allowed to redirect from 5 to 50 % of the total volume of air produced by the turbocharger. It should be noted that the valve discharged only excess air, which is the source of negative pulsations. Therefore, the air flow through the cylinders of the piston engine was maintained.

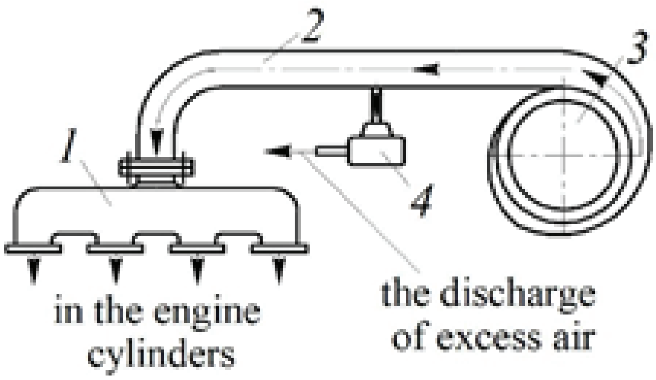

Figure 2: The schema of the intake system of the piston engine with the vent system of charge air after turbocharger: *1* – intake manifold; *2* – connecting pipe; *3* – turbocharger; *4* – electro-pneumatic valve.

4. The main results of experimental studies

It is established that the decrease of velocity and pressure fluctuations flow occurs due to the discharge of certain parts of charge air from intake system (Figure 3). This reduction is up to 2.5 times in some operation modes of the engine and turbocharger.

The discharge of a certain portion of the charge air leads to a decrease in the pulsation phenomena in the intake system during the entire working cycle of the piston engine with a turbocharger (Figure 3 *a*). The enlarged section of the dependence $p_x = f(\varphi)$ after closing the intake valve is shown in Figure 3 *b*. It more clearly shows the stabilization of the flow (reduction of pulsations of the flow pressure) in the intake system. For example, the discharge of a certain portion of the charge air causes a reduction in the flow pressure pulses in the intake system by about 40 % at a crankshaft speed n = 1500 rpm and a turbocharger rotor n_{TC} = 42 000 rpm (Figure 3 *b*).

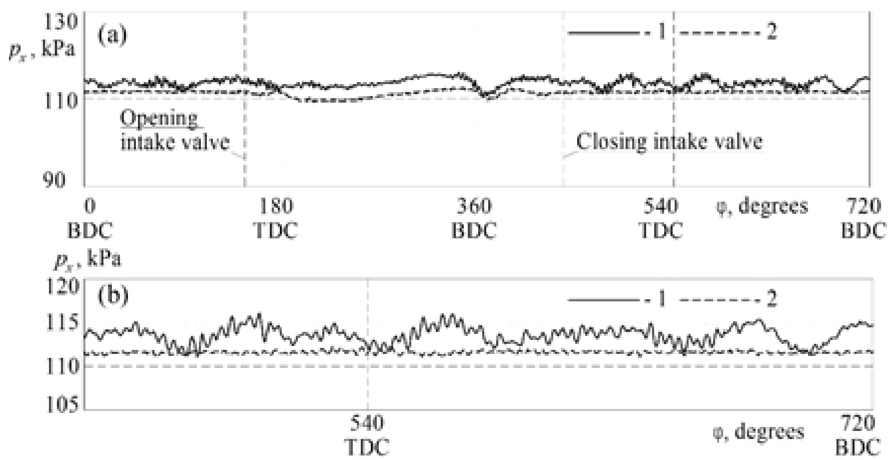

Figure 3: The dependences of the pressure p_x of the air flow in the intake system of the piston engine with a supercharger without air vent (1) and with air vent (2) from the crankshaft angle φ for the rotational speed of crankshaft n = 1500 rpm and the rotor of turbocharger n_{TC} = 42 000 rpm: (*a*) for the entire working cycle of a piston ICE; (*b*) plot after the closing valve.

The intensity of local heat transfer significantly changes with a controlled discharge of a certain part of the charge air from the intake system (Figure 4).

It was found that the decrease in the heat transfer rate reaches 38% during the open intake valve period at speeds of n = 3000 rpm and n_{TC} = 35 000 rpm. Probably, this is due to a sharp decrease in the intensity of turbulent pulsations in the intake system of the piston engine.

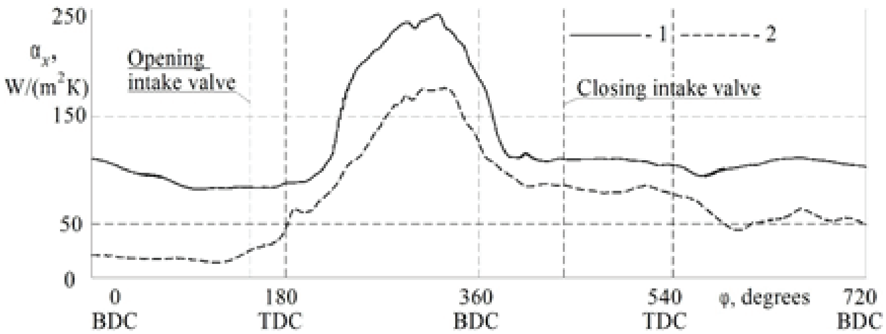

Figure 4: The dependence of the local heat transfer coefficient α_x in the intake system of the piston engine with a supercharger without air vent (1) and with air vent (2) from the crankshaft angle φ for the rotational speed of crankshaft n = 3000 rpm and the rotor of turbocharger n_{TC} = 35 000 rpm.

5. The practical application of research results

The achieved effects of stabilizing flows in the intake system will reduce the differences in the operation of the cylinders of the multi-cylinder engine, reduce the noise level, increase the reliability of the piston engine, and also increase the efficiency of the compressor. The optimal values of the air discharge, depending on the rotational speeds of n and n_{TC}, were determined to achieve the maximum effect of reducing pulsations. The algorithm for automatic control of the electro-pneumatic valve was developed. The root-mean-square value of the flow pressure pulsations in the intake system of a piston engine with a turbocharger was used as a control parameter in this algorithm.

The design of the intake system with an electro-pneumatic valve for the controlled discharge of a part of the charge air for the diesel engine 8DM-21 produced by the Ural diesel-motor plant is shown in Figure 5.

Russian Federation patent was received on the intake system with the vent system of charge air of the piston engine with turbocharging [12].

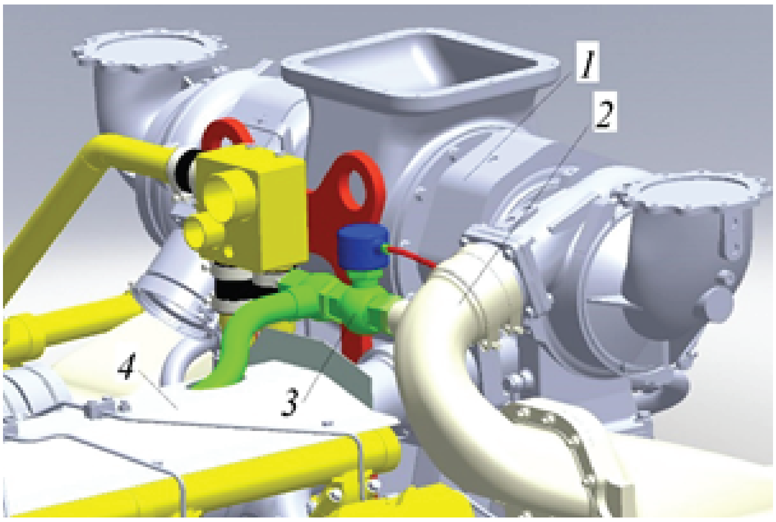

Figure 5: The intake system of the diesel engine DM-21 (Ural diesel-motor plant) with the vent system of charge air: *1* – turbocharger; *2* – connecting pipe; *3* – electro-pneumatic valve; *4* – cover of an exhaust manifold.

6. Conclusions

The following main conclusions can be drawn based on the results of research of thermal and mechanic flow characteristics in the intake system of the piston engine with turbocharging:

- the basic laws of change of the instantaneous local values of velocity and pressure of air flow and local heat transfer coefficient in the intake system of the piston internal combustion engine with a turbocharger for different engine and turbocharger operation mode were established;
- method of reducing (up to 2.5 times) the pressure and flow rate pulsations of air in the intake system of the piston engine with a turbocharger and method of reducing the local heat transfer coefficient on average by 25 % were developed; This will reduce the differences in the cylinders operation of the multi-cylinder engine, reduce the noise level and increase the reliability of the piston ICEs;
- design of the intake system with an electro-pneumatic valve for the diesel engine 8DM-21 (Ural diesel-engine plant) was developed.

Acknowledgments

The work has been supported by the Russian Foundation for Basic Research (grant No. 16-38-00004).

References

[1] Draganov B H, Kruglov M G and Obuhova V S 1987 *The design of the intake and exhaust ducts of internal combustion engines* (Kiev: Vishcha shkola publ.) p 175

[2] Corky H 1997 *Maximum boost: designing, testing and installing turbocharger systems* (USA: Robert Bentley Publishers) p 250

[3] Heywood J B 1988 *Internal combustion engine fundamentals* (New York: McGraw-Hill) p 458

[4] Zhilkin B P, Lashmanov V V, Plotnikov L V and Shestakov D S 2015 *Process improvement in gas-air path of piston internal combustion engines* (Ekaterinburg: Ural Press) p 228

[5] Teregulov T I, Chernousov A A 2013 *Dvigatelestroen.* **3** 28–32

[6] Watson N, Janota M S 1982 *Turbocharging the internal combustion engine* (Hong Kong: Mechanical Press Ltd) p 362

[7] Dixon S L 1998 *Fluid mechanics and thermodynamics of turbomachinery* (Oxford: Butterworth-Heinemann) p 285

[8] Kraev V M, Tihonov A I 2011 *Newsletter of the Russian Academy of Sciences* **1** 112–118

[9] Valueva E P, Kulik A A 2006 *Thermal Engineering* **5** 50–55

[10] Park J S, Taylor M F, McEligot D M 1982 *Proc. 7th Intern. Heat Transfer Conf.* vol 3 pp 105–110

[11] Zhilkin B P, Shestakov D S, Plotnikov L V 2012 *Tyazh. Mashinostr.* **2** 48–51

[12] Zhilkin B P, Plotnikov L V, Shestakov D S 2012 Patent 118363 RU